On the Physiology of Wings: being an Analysis of the Movements by which Flight is produced in the Insect, Bat, and Bird. By James Bell Pettigrew, M.D., F.R.S. Communicated by Professor Turner.

(*Abstract.*)

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In the present memoir the author enters very fully into *the figure-of-*8 *wave movements*, described by the wing in space, to which he first directed attention in March 1867.* He has adduced the experiments with *natural* and *artificial wings*, on which his description was originally based, and has shown, by the aid of original models and a large number of diagrams and drawings, that *artificial wings* can be made to approach indefinitely near to *natural ones*, not only in their structure, but also in their movements. He further points out that the fins and tail of the fish—the flippers and caudal extremity of the whale, dugong, manatee, and porpoise, and the flippers of the seal, sea bear, walrus, and turtle—bear a close analogy to wings, and ought to be studied in connection with them. As further proof that the wing describes a figure-of-8 wave-track in flight, the author cites the results announced in February 1869 by Professor J. E. Marey, of Paris.†

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* *Vide* "The Various Modes of Flight in Relation to Aëronautics;" by the Author in the "Proceedings of the Royal Institution of Great Britain for March 22, 1867;" also his memoir "On the Mechanical Appliances by which Flight is attained in the Animal Kingdom," read to the Linnean Society of London on the 6th and 20th of June 1867, and published *in extenso* in the 26th volume of their Transactions, a large number of woodcuts and engravings being specially devoted to the elucidation of the figure-of-8 wave track made by the wing as observed in the flight of the insect, bat, and bird.

† "Revue des Cours Scientifiques de la France et de l'Etranger." Professor Marey, in a letter addressed to the French Academy, under date May 16, 1870, fully acknowledges the author's claim to priority (as regards himself) in the discovery of *the figure-of-*8 *wave movements made by the wing in flying*. M. Marey, in the letter referred to, states ("Comptes Rendus," page 1093, May 16, 1870), "J'ai constaté qu' effectivement M. Pettigrew a vu avant moi, et représenté dans son Mémoire, la forme en 8 du parcours de l'aile de l'insecte: que la méthode optique à laquelle j'avais recours est à peu près identique à la sienne . . . . . je m' empresse de satisfaire à cette demande légitime, et je laisse entièrement la priorité sur moi, à M. Pettigrew relativement à la question ainsi restreinte."

Professor Marey, by employing a sphygmograph similar to that used for ascertaining the state of the pulse, succeeded in causing the wings of insects and birds to register their own movements. He says:—“But if the frequency of the movements of “the wing vary, the *form* does not vary. It is invariably the same; “it is always *a double loop, a figure of* 8. Whether this figure be “more or less apparent, whether its branches be more or less equal, “matters little; it exists, and an attentive examination will not fail “to reveal it.” *

The subjoined are a few of the results obtained by the author in the course of his numerous observations and experiments:—

The wing is of a generally triangular form. It is finely graduated, and tapers from the root towards the tip, and from the anterior margin towards the posterior margin. It is likewise slightly twisted upon itself, and this remark holds true also of the primary or rowing feathers of the wing of the bird. The wing is convex above and concave below, this shape, and the fact that in flight the wing is carried obliquely forward like a kite, enabling it to penetrate the air with its dorsal surface during the up stroke, and to seize it with its ventral one alike during the down and up strokes. The same remark applies to the *remiges* or rowing feathers of the wing of the bird.

The wing is moveable in all its parts; it is also elastic. Its power of changing form enables it to be wielded intelligently, even to its extremity; its elasticity prevents shock, and contributes to its continued play. The wing of the insect is usually in one piece,† that of the bat and bird always in several. The curtain of the wing is continuous in the bat, because of a delicate elastic membrane which extends between the fingers of the hand and along the arm; that of the bird is non-continuous, owing to the presence of feathers, which open and close like so many valves during the up and down strokes.

The posterior margin of the wing of the insect, bat, and bird, is rotated *downwards and forwards* during extension, and *upwards*

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* Revue des Cours Scientifiques de la France et de l’Etranger, p. 252. 20th March 1869.

† The wings of the beetles are jointed, so that they can be folded up beneath the elytra or wing cases.

and backwards during flexion. The wing during its vibration descends farther below the body than it rises above it. This is necessary for elevating purposes.

The distal portion of the posterior margin of the wing of the insect is twisted in a downward and *forward direction* at the end of the down stroke, whereas, at the end of the up stroke it is twisted downwards and *backwards*. The proximal portion of the posterior margin always assumes a reverse position to that occupied by the distal portion, so that the posterior and anterior margins of the wing are not in the same plane, and in certain situations the two margins appear to cross each other. What is here said of the insect's wing applies equally to the wings of the bat and bird.

The wing during its vibrations *twists* and *untwists*, so that it acts as a reversing reciprocating screw. The wing is consequently a screw *structurally* and *functionally*.

The blur or impression produced on the eye by the rapidly oscillating wing *is twisted upon itself*, and resembles the blade of an ordinary screw propeller.

The twisted configuration of the wing and its screwing action are due to the presence of *figure-of*-8 *looped curves* on its anterior and posterior margins; these curves, when the wing is vibrating, reversing and reciprocating in such a manner as to make the wing change form in all its parts. The curves in question are produced to a great extent by vital movements, independently alike of the elasticity of the wing and the reaction of the air. They can, however, be produced by the latter agencies likewise. The change and reversal of the curves occurring on the anterior and posterior margins cause the different portions of the wing to strike at various angles during the down and up strokes.

The angles which the different parts of the wing make with the horizon are greatest towards the root, and least towards the tip of the wing. The angles are, in fact, adjusted to the speed at which the different portions of the wing travel—a large angle with a low speed giving the same amount of buoying and propelling power as a small angle with a high speed.

The speed attained by the tip of the wing is always very much higher than that attained by those portions nearer the root—the root corresponding to the *short* axis of rotation. (The *long* axis of rotation runs along the anterior margin of the wing.)

The angles which the wing makes with the horizon are increased during the down stroke, and decreased during the up stroke, the posterior margin of the wing being screwed down upon the air during the down stroke to increase the elevating and propelling power of the wing, and unscrewed or withdrawn from the air during the up stroke to afford support, and assist in propulsion.

The wing, in virtue of the variations of inclination of different parts of its surface, acts as a true kite during both the down and up strokes, *i.e.*, it flies down and up alternately in such a manner as to keep its ventral concave or biting surface always closely applied to the air. The wing is, therefore, effective during both the *down* and *up strokes*, so that it is a mistake to regard the down stroke as alone contributing to flight. In reality the down and up strokes are parts of one movement, the wing describing first a looped and then a wave track.

The tip of the wing in especial acts as a kite during the up stroke, the kite being inclined upwards, forwards, and outwards.

The kite formed by the wing differs from the boy's kite in being capable of change of form in all its parts. The change of form of the wing is rendered necessary by the fact, that the wing is articulated or hinged at its root (short axis), its different parts, as a consequence, travelling at various degrees of speed in proportion as they are removed from the axis of rotation. It is also practically hinged along its anterior margin (long axis), so that the tip travels at a higher speed than the root, and the posterior margin than the anterior. The compound rotation and varying degree of speed attained by the different parts of the wing has the effect of twisting the wing upon its long axis, and producing a variety of kite-like surfaces calculated to operate effectually upon the air, whatever the position of the wing may be.

The wing, when the flying animal is fixed or hovering steadily before an object, describes a figure-of-8 wave track in space,—the figure-of-8, when the animal flies in a horizontal direction, being opened out or unravelled to form first a looped and then a waved track.

In horizontal flight the wing describes a series of large waves or curves, the body describing a series of smaller and opposite curves, the wing always rising when the body falls, and *vice versa.* The descent of the wing in this manner necessitates the elevation of the body, and the descent of the body contributes to the elevation of the wing.

The wing elevates the body when it descends, and the body, when elevated, falls forwards in a curve, and so contributes to the elevation of the wing. This arrangement draws the wing forward upon the air during the up stroke, and opposes the direct downward action of gravity by presenting the concave or biting surface obliquely to the air in the direction of the travel of the body. The under surface of the wing is thus made to act as a true kite during the up stroke.

The wing is urged at different velocities, the power applied being much greater during the down stroke than during the up one. The power is also greater at the beginning of the down and up strokes than towards the termination of those acts. The variation in the intensity of the driving power is necessary to slow the wing towards the termination of the down stroke, to prepare it for the up stroke, and to afford the air an opportunity of reacting on the under surface of the wing, to the elevation of which it contributes. The wing is elevated more slowly than it is depressed, and allows the body time to fall downwards, the fall of the body assisting in elevating the wing relatively to the bird. The wing, the air, and the weight of the body, are consequently active and passive by turns.

The wing is depressed by voluntary muscular efforts. It is elevated by vital, and mechanical acts, viz., by the contraction of the elevator muscles and elastic ligaments, by the reaction of the air called into play by the fall and forward travel of the body.

If the wing is in one piece, it is made to vibrate figure-of-8 fashion in a more or less *horizontal direction.* It thus attacks the air by a series of zig-zag movements, very similar to those performed by an overloaded dray-horse when ascending a hill. If the wing is in more than one piece, it is made to oscillate in a more or less *vertical direction ;* the wing, under these circumstances, being usually closed during the up stroke and opened out during the down stroke. The wing is closed and its area diminished during the up stroke, expressly to avoid the resistance of the air.

The wing of the insect is, in some cases (the wasp, for instance), folded upon itself during the back stroke to avoid the resistance of the air; in other cases, when two pairs of wings are present (the butterfly, for example), the first pair of wings is made to overlap the second pair for a similar purpose.

When the wing is in one piece, and made to vibrate in a more or less horizontal direction, it is followed in its passage from right to left by a current which the wing meets in its passage from left to right. When the wing passes from left to right it is followed by a current which the wing meets in its passage from right to left, and so on. The wing has therefore the power of creating the current on which it rises.

When the wing is in several pieces, and made to vibrate more or less vertically, one portion of the pinion (during the acts of extension and flexion) makes a current which another portion utilises. Thus the tip and root of the wing (hand and arm) make a current during extension on which the middle part of the wing (fore-arm) acts during flexion, and the reverse. This arrangement begets a cross pulsation, and extends in the bird even to the primary and secondary feathers. The wing may thus be said to rise upon a whirlwind of its own forming.

The wing has the power of producing artificial currents, and of utilising and avoiding natural currents, so that it is equally adapted for flying in a calm and in a storm. As the wing (or parts of the wing) strikes in opposite directions, it in this manner reciprocates, the down stroke running into and contributing indirectly to the efficacy of the up stroke, and the reverse. The down and up strokes consequently form one continuous act, and neither is complete without the other. The down stroke produces the current on which the wing operates during the up stroke, and *vice versa.*

The reciprocation of the wing is most perfect when the animal is fixed in one spot, and least perfect when it is flying at a high horizontal speed. It is, however, a matter of indifference whether the wing attacks the air or the air attacks the wing, so long as a sufficient quantity of air is worked up under the wing in any given time.

The wing of the bat and bird are drawn towards the body and flexed at the termination of the down stroke to destroy the momentum acquired by the pinion during its descent, and to prepare it for making the up stroke. It is elevated as *a short lever* to avoid the resistance of the air, and pushed away from the body or extended towards the end of the up stroke to prepare it for making the down stroke. It is depressed with great energy as *a long lever*, and hence the greater elevating and propelling power of the down as compared with the up stroke.

When the bat and bird are stationary, the tip of the wing, from its alternately darting out and in, and forwards and backwards, during extension and flexion, and during the down and up strokes, describes an ellipse, the axis of which is inclined obliquely *upwards* and forwards. When the bat and bird are progressing at a high speed, the axis of the ellipse is inclined obliquely *downwards* and forwards, the ellipse itself being converted into a spiral and then a wave line. The outward and forward (extension) and inward and backward (flexion) play of the pinion contributes to the balancing power of the bat and bird, as it augments the horizontal area of support.

The wing of the insect is recovered or drawn towards the body, and that of the bat and bird recovered, flexed, and slightly elevated by the action of elastic ligaments. Those ligaments, by their contraction, conserve and interrupt muscular efforts without destroying continuity of motion.

The elastic ligaments are in many cases furnished with muscular fibres, and are most highly differentiated in those animals whose wings vibrate the quickest.

The primary, secondary, and tertiary feathers of the wing of the bird are geared to each other by fibrous structures in such a manner that the feathers are made to rotate in one direction during flexion, and in another and opposite direction during extension. The double rotation of the feathers in question confers a distinctly valvular action on the wing of the bird.

The under surface of the wing of the bat and bird is thrown into a beautiful arch during extension and the down stroke, the arch being so formed that its tension increases according to the pressure applied.

The wing is inserted into the upper part of the thorax, and balances the body by playing alternately above, beneath, and on a level with it. When above the body, the latter is suspended from the wings as from a parachute. When beneath the body, it is suspended from the top of a cone formed by the wings, and when on a level with the body, the latter is placed in the centre of a circle described by the rapidly oscillating wings. The body is suspended from the wings very much as a compass set upon gimbals is suspended.

The wing balances the body in consequence of its travelling at such a speed as enables it to convert the area mapped out by its vibrations into what is practically a solid basis of support.

The wing, whether in one piece or in many, rotates upon two centres, the one centre corresponding to the root of the wing (short axis), the other to the anterior margin (long axis). The rowing feathers have a similar compound motion. This mode of action of the wing is intimately associated with the power it enjoys of alternately seizing and evading the air, of producing artificial currents, and of utilising artificial and natural currents.

The wing is cranked slightly forwards, a small degree of rotation of the anterior margin being followed by a very considerable sweep of the posterior margin.

The wing area is greatly in excess of what is absolutely necessary, and as much as four-sixths may be removed in certain insects (the common blow-fly, *e.g.*), without destroying the power of flight. The wing area may also be considerably reduced in birds without in any way impairing flight. This shows that elaborate calculations of wing area, in relation to weight of trunk, must prove futile, unless the rapidity with which the wing vibrates and the state of the air are also taken into account.

Weight is necessary to the flight of the insect, bat, and bird, as at present constructed. If flying creatures were lighter than the air, the wing would require to be twisted completely round as in the auks and penguins, so that the under ventral or concave surface would strike from below upwards, instead of from above downwards.

In aërial flight the under or concave surface of the wing is applied *from above*, whereas in subaquatic flight it is applied *from below*. The scull, like the subaquatic wing, is applied from below, so that the analogy between the aërial wing and the oar as employed in sculling is more apparent than real.

A diving bird which flies under the water *is lighter than the water*, and flies *downwards*. A bird which flies in the air *is heavier than the air*, and flies *upwards*. Relative levity and weight are therefore necessary to the diving and flying bird as at present constituted.

Weight, when associated with or operating upon wings, contributes to horizontal flight. A flying animal, when it drops from a height with expanded motionless wings, does not fall vertically downwards, but downwards *and forwards*, the wings converting what would otherwise be a vertical fall of the body partly into *forward travel*. The weight of the body thus to a certain extent relieves the muscular system from excessive exertion. If a sufficient breeze be blowing, the weight of the trunk and the breeze upon the wings operating conjointly are sufficient to keep the body of the animal in the air for protracted periods. This is well seen in the case of the albatross, which can sail about for an hour at a time when there is wind without once flapping its wings.

The wing, as a rule, is more flattened in the insect than in the bat and bird. It is, moreover, driven at a higher speed, those animals which fly the quickest having for the most part the flattest wings. The dragon fly furnishes a good example.

The greater the concavity of the wing, the greater the elevating power; the flatter the wing, the greater the propelling power.

The wings in living animals are thoroughly under control both during the down and up strokes; the wing, consequently, is not simply an elastic apparatus, which derives the movements of its separate parts from the air; on the contrary, it directs and controls the air in such a manner as to extract the maximum of support and propulsion from it.

The wings of bats and birds are moved by direct muscular action in combination with certain *elastic* ligaments, and the same holds true of the dragon fly and some other insects. The elasticity of the wing and the resiliency and reaction of the air, however, assist the muscles and ligaments.

The great speed attained by the tip and body of the wing is due to the fact that the wing is articulated or jointed at its root, any movement communicated at the root being quickened in proportion to the distance from the root. In other words, a comparatively slow movement communicated to the root of the wing is at once converted into a very rapid one at the tip.

If an artificial wing be constructed in strict accordance with any of the natural wings (insect, bat, or bird), and applied by a sculling figure-of-8 movement to the air, it will be found to supply a steady buoying and propelling power, similar in all respects to that supplied by the living wing.

In order to secure this result, the artificial wing should be concavo-convex, and slightly twisted upon itself, *i.e.*, it should be finely arched in every direction. It should be mobile as well as elastic,* and be applied to the air at different angles and at different degrees of speed, in such a manner that the wing and air may be active and passive by turns.

The *artificial wing*, like the natural one, must be more or less triangular in shape. It must taper from the root towards the tip, and from the anterior margin in the direction of the posterior margin. It should be capable of change of form, and elastic throughout, the flexibility being greatest at the tip and posterior margin of the wing, and least at the root and along the anterior margin. It must move in all its parts at different periods of time, as in this way the air is alternately seized and dismissed, dead points avoided, and a continuous reciprocating movement secured. In producing a continuous vibration of the artificial wing, much assistance is obtained by employing a ball-and-socket joint at its root, with a system of elastic springs of different strengths. The principal springs should be arranged at right angles to each other, the superior and posterior springs being stronger than the inferior and anterior ones. Oblique springs may be added, and the whole, because of their different strengths and their peculiar directions and insertions, can be made to give the wing any amount of torsion in the direction of its length during every portion of either the up or down stroke. The muscles and elastic ligaments of insects, bats, and birds, perform a similar function. A ball-and-socket joint, or what is equivalent thereto, is necessary at the root of the wing, because the pinion should be free to move in an upward, downward, forward, and backward direction. It should also be able to rotate around its anterior margin to the extent of nearly a quarter of a turn. All the movements referred to are derived in the author's models from a *direct piston action*, from the reaction of the air, the elasticity of the wings and springs, and the weight of the machine bearing the wings. They are restrained and directed by the gearing apparatus extending between the piston and the wings, but more especially by the different lengths, strengths, and directions of the elastic springs themselves. The piston is made to descend with a very violent hammer-like motion at the beginning of the down stroke, the movement being gradually slowed as the wing descends to a certain point, at which the movement is reversed and the piston ascends more slowly, its ascent being occasioned for the most part by the reaction of the air, the elasticity of the wing and of the springs at its root, and by the descent of the engine propelling the wings. The driving power, the weight of the apparatus, the recoil of the air, and the elasticity of the wings and springs are thus made to act in concert, the different forces being active and passive at intervals, and no two forces acting together at precisely the same instant of time.

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* Borelli (1668), Durkheim, and Marey state that an artificial wing should be composed of a *rigid rod* in front and a flexible sail behind, but experiment has convinced the author that no part of the wing should be absolutely rigid.

If a longitudinal section of a bamboo cane, 10 feet in length and half-an-inch in breadth, be taken by the extremity and made to vibrate, it will be found that a wavy serpentine motion is produced in it, the waves being greatest when the vibration is slow, and least when it is rapid. It will further be found that, at the extremity of the section where the impulse is communicated, there is a steady reciprocating movement devoid of dead points. The continuous movement in question is no doubt due to the fact that the different portions of the reed reverse at different periods, the undulations induced in the reed being to an interrupted or vibratory movement very much what the continued play of a fly-wheel is to a rotatory motion.

If a similar reed has added to it at its outer or distal half tapering rods of whalebone radiating in an outward and backward direction to the extent of a foot or so, and the whalebone and the reed be covered with a thin sheet of india-rubber, an artificial wing resembling the natural one in all its essential properties is at once produced.* Thus if the wing be made to vibrate at its root, *a double wave is produced*, the one wave running in the direction of the length of the wing, the other in the direction of its breadth. The wing further *twists* and *untwists* figure-of-8 fashion during the down and up strokes. There is, moreover, a continuous play of the wing, the down stroke gliding into the up one, and *vice versa*, by a system of continuous and opposite curves, which clearly shows that the down and up strokes are parts of one whole, and that neither is perfect without the other. This form of wing is endowed with the very remarkable property that it will fly in any direction, demonstrating more or less conclusively that flight is essentially a *progressive wave movement.* Thus if the anterior or thick margin of the wing be directed upwards, and the angle which the under surface of the wing makes with the horizon be something less than 45 degrees, the wing will, when made to vibrate, fly with an undulatory motion *in an upward direction*, like a pigeon to its dove-cot. If the under surface of the wing make no angle, or a very small angle with the horizon, it will dart forward in a series of curves *in a horizontal direction*, like a crow in rapid horizontal flight. If the angle made by the under surface of the wing be reversed, so that the anterior or thick margin of the wing be directed downwards, the wing will describe a wave track and fly *downwards*, as a sparrow from the top of a house or tree. In all those movements *progression* is a necessity; the movements are continuous gliding *forward movements ;* there is no halt or pause between the strokes, and if the angle which the wing makes with the horizon be sufficiently great, the amount of steady, *tractile*, and *buoying power* developed is truly astonishing. This form of wing elevates and propels both during the down and up strokes, and its working is accompanied with little or no slip. Its movements may be regarded as the literal realisation of the figure-of-8 hypothesis of flight.

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* The author has made a great variety of artificial wings. Of these some are in one piece, with a continuous covering ; others in a single piece, with the cover broken up into a large number of small valves ; others in several pieces, with a continuous covering, and others jointed, with the cover broken up into a number of valvular segments. In all cases the frames of the wings are composed of *elastic material*, such as steel tubes, bamboo and other canes, osier twigs, whalebone, gutta percha, &c., &c. ; the covers of the wings are made of india-rubber cloth, tracing cloth, argentine, linen, silk, &c., &c. ; the springs of the wings of steel, caoutchouc, &c., &c.

If the artificial wing be in one piece, it ought to be made to vibrate in a more or less horizontal direction ; if in several pieces, it should be worked in a more or less vertical direction, as the wing in this case acts alternately as a short and long lever, in virtue of its closing and opening during the up and down strokes, the acting area of the wing being greatly reduced during the up stroke, and greatly increased during the down one.

If a properly constructed artificial wing be made to vibrate in a vertical direction, it invariably darts *downwards and forwards in a curve* during the down stroke, and *upwards and forwards* in a *similar* but *opposite curve* during the up stroke, the two curves running into each other to form a progressive, continuous, *wave track.*

If the wing be made to vibrate from side to side in a more or less horizontal direction, it rises zig-zag fashion by a series of looped curve movements, each pass of the wing being on a higher level than that which preceded it. Whether the wing be moved vertically or horizontally, it invariably twists and untwists during its action. In twisting and untwisting, it developes figure-of-8 curves, not only along its anterior and posterior margins, but throughout its entire length and breadth.

The figure-of-8 vertical movement may be converted into the figure-of-8 horizontal movement by a slight rotation of the wing on its long axis, or by a tilt of the body or frame bearing the wing. It is in this way that the wing may act either as an elevator and propeller, or merely as an elevator. Thus it is not uncommon to see an insect elevate itself by a horizontal screwing figure-of-8 movement, and then, suddenly changing the direction of the stroke of the wing and of the body, dart forward in a nearly horizontal direction.

The artificial wing, like the true one, attacks the air at a great variety of angles during the down and up strokes. Thus during the down stroke the angles which the wing makes with the horizon are increased, whereas during the up stroke they are diminished.

The angles made by the different portions of the artificial wing vary as in the living wing, the angles made by the parts nearest the root being greater than those nearer the tip. This is occasioned by the manner in which the artificial wing *twists* and *untwists* during its action, the torsion in question being due to the elastic properties of the wing and the resistance which it experiences from the air, as well as to the fact that the tip and posterior part of the wing travel at a much higher speed than the root and anterior part. The small angle made by the tip, as compared with the root of the wing, equalises its action, a large angle urged at a low speed giving the same amount of buoyancy and propelling power as a smaller angle urged at a higher speed.

The artificial wing, because of its elasticity and by the aid of certain springs, can be made to slow and reverse of its own accord at the end of the down and up strokes in precisely the same manner as the natural wing. It can likewise be made to change its course without halt or dead point, so as to give continuity of motion and continued buoyancy.

If the artificial wing be moved figure-of-8 fashion in a more or less horizontal direction, it can be made to create and utilise its own currents, the stroke from right to left producing the currents on which the wing rises in its passage from left to right, and the reverse. It can also be made to utilise and evade natural currents.

If the tip of a properly constructed artificial aërial wing be turned downwards, and the wing be made to move from side to side figure-of-8 fashion like the tail of a fish, it forms a very excellent aërial propeller.

The artificial wing, to be effective, must rotate about two separate axes, the one corresponding to its root (short axis), the other to its anterior margin (long axis).

If two artificial wings, similar to those described, be placed end to end, inclined at a certain upward angle, and made to revolve, they form a most powerful aërial screw. This form of screw is propelled with comparatively little force, and its working is attended with quite a nominal amount of slip.

The aërial screw here recommended *is elastic* and *capable of change of form* in all its parts, and so constructed that its angles vary to adapt themselves to the speed attained by the different portions of the blades at any given time. Thus the angles made by the blades are greatest when the speed at which the screw is driven is least, and *vice versa ;* the angles made by those portions of the blades which are nearest the axis of rotation being always greater than those made by the portions nearer the tips of the blades. This form of aërial screw differs widely from the aerial screws at present in use, and from the screw propeller employed in navigation, inasmuch as it is moveable in all its parts, and adjusts itself to its work in such a manner as to secure the maximum of elevating and propelling power, with a minimum of slip. The screw propeller and aerial screws as at present employed are, on the contrary, *rigid and unyielding*, and possess no accommodating power. As a consequence, much propulsive power is sacrificed in slip.

If the blades of the aërial screw referred to be greatly diminished in size, and formed of carefully tapered, finely graduated steel plate, it operates with remarkable efficiency in water, the elasticity of the screw diminishing the slip, while it greatly augments the propelling power.